Wearable sensor metric for fidgeting: screen engagement rather than interest causes NIMI of wrists and ankles

Joe D. Chalkley †
Brighton & Sussex Medical School
Brighton BN1 9RY, UK
J.Chalkley1@uni.bsms.ac.uk

Thomas T. Ranji †
Brighton & Sussex Medical School
Brighton BN1 9RY, UK
t.ranji1@uni.bsms.ac.uk

Carina E. I. Westling
School of Media, Film & Music
University of Sussex
Brighton BN1 9RG, UK
c.e.i.westling@sussex.ac.uk

Nachiappan Chockalingam
CSHER, Faculty of Health,
Staffordshire University
Stoke-on-Trent ST4 2DF, UK
n.chockalingam@staffs.ac.uk

Harry J. Witchel
Brighton & Sussex Medical School
Brighton BN1 9RY, UK
h.witchel@bsms.ac.uk

† These two authors contributed equally

ABSTRACT

Measuring fidgeting is an important goal for the psychology of mind-wandering and for human computer interaction (HCI). Previous work measuring the movement of the head, torso and thigh during HCI has shown that engaging screen content leads to non-instrumental movement inhibition (NIMI). Camera-based methods for measuring wrist movements are limited by the occlusion, supination and friction of the arm. Here we used a high pass filtered magnitude of wearable tri-axial accelerometer recordings during 2-minute passive HCI stimuli as a surrogate for movement of the wrists and ankles. With 24 seated, healthy volunteers experiencing HCI, this metric showed that wrists moved significantly more than ankles. We found that NIMI could be detected in the wrists and ankles; it distinguished extremes of interest and boredom via restlessness. We conclude that both free-willed and forced screen engagement can elicit NIMI of the wrists and ankles.

Author Keywords

fidgeting; micromovements; postural change; non-exercise activity thermogenesis; NEAT; accelerometry; boredom.

ACM CLASSIFICATION KEYWORDS

HCI design and evaluation methods: Laboratory experiments

General Terms

Human Factors; Affective computing; Measurement.

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INTRODUCTION

Importance of Movement to Cognitive Ergonomics

Wearable sensors can recognise specific activities in people, although fidgeting interferes with accuracy [4]. Movement and fidgeting are increasingly accepted as surrogate metrics for engagement (and boredom) when interacting with digital interfaces [8; 3]. In particular, screen engagement, which is in part related to subjective interest, is associated with non-instrumental movement inhibition (NIMI) [7]. These measurements of micromovements are also important for the psychology of mind wandering, as well as for the physiology of non-exercise activity thermogenesis (NEAT).

Previous technologies for measuring seated movements during digital interactions have included pressure mats, video tracking and analysis, opto-electronic systems, Wii balance boards, and subjective judgements by experts. These techniques have generally provided measurements of movement of the head, the trunk or an omnibus measure of whole body movement. All these systems have weaknesses when attempting to measure the wrist; the wrist's supination makes optical occlusion of markers likely, and the fact that the wrist often rests on the thigh means that markers can be displaced by friction. Also, the presence of a desk during traditional HCI means that occlusion is likely, even with multi-camera opto-electronic systems.

Here, our team looked at the accelerometry magnitudes from wearable sensors mounted on the wrists and ankles of healthy participants during two-minute stimuli ranging from highly boring to highly engaging. As a control stimulus, we included a boring "forced engagement" task in which the participant was instructed to stare at cross hairs for two minutes. Our experimental questions were: A) can NIMI be detected at the wrists and ankles using wearable sensors, and B) does forced engagement lead to NIMI?

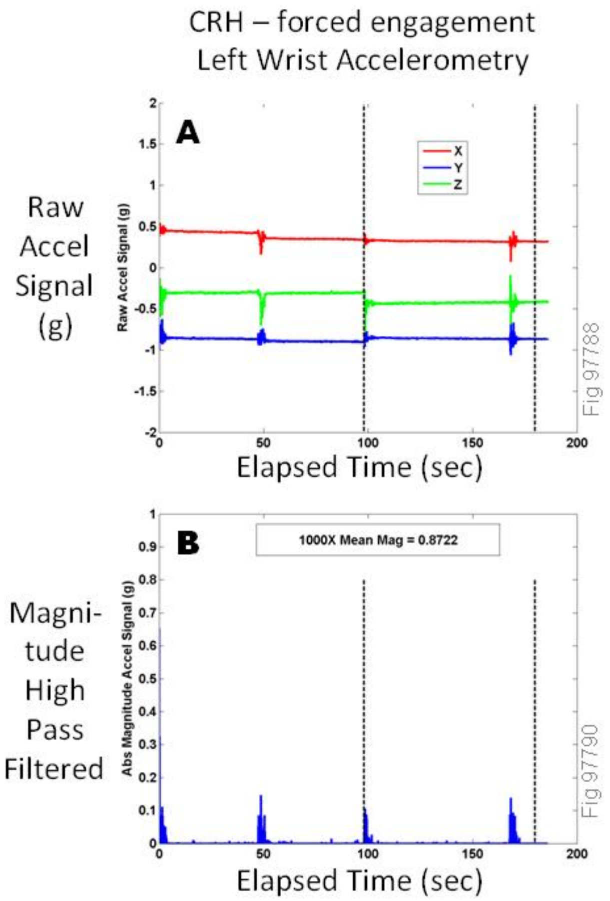


Figure 1. Representative data for accelerometer-based movement of the left wrist for occasional fidgeting. The participant (Y114) was experiencing the control stimulus (CRH), which is not interesting but incorporates forced engagement. In panel A, the raw data for all three axes (X,Y,Z) of acceleration are shown. The sensor is worn in the position of a wrist watch, and in anatomic position, X is distal to proximal, Y is right to left, and Z is ventral to dorsal. The plot shows all 180 seconds of the experience, but for calculations only 80 seconds of data (between the dashed vertical lines) are used. Panel B shows the absolute value for high-pass filtered (5 Hz) data for the magnitude of the data in panel A, which is calculated as the square root of the sum of the squares at each point. The mean magnitude shown at the top of panel B is the mean value of all points between the dashed vertical lines, multiplied by 1000 (for clarity).

METHODS

Experimental Participants

Twenty-four healthy volunteers (all right-handed, 12 female, mean age ± SD = 27.0 ± 1.7), mostly students, were recruited via an email to the university community and received £20 for their travel and/or time. This study was carried out in accordance with the approval of BSMS's Research Governance and Ethics Committee. All participants gave written informed consent in accordance with the Declaration of Helsinki.

Protocol

The complete methodological description can be found in [6; 8]. Participants were seated in a standard armless chair at a desk with a 21.5 inch monitor. The monitor was set up with the centre of the screen at the eye level of the volunteer. Volunteers were allowed to adjust the seat position for comfort. Participants experienced audiovisual stimuli in a counterbalanced order, each lasting 170 seconds, and immediately afterward rated the experience via a subjective questionnaire. Participants were fitted with sensors on the left and right wrists and ankles, and on the sternum (sternum results are not reported here). They were also fitted with reflective tracking markers and were filmed from the lateral aspect (results are not reported here). During the stimuli, participants were alone in the room.

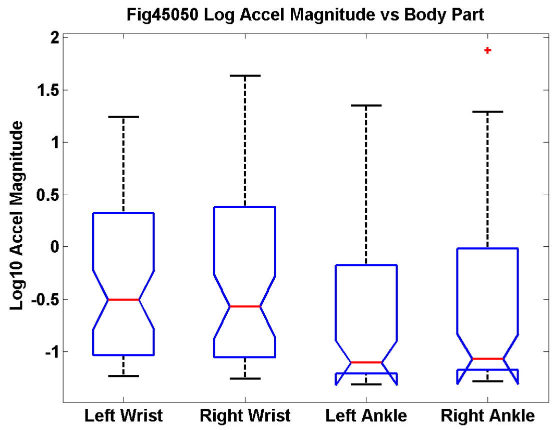


Figure 2. Wrists fidget more than ankles. Y axis shows log10 of mean high pass filtered (5 Hz) magnitude of accelerometry signals. All data is matched (i.e. the same participants experiencing the same stimuli). Left wrist and right wrist are not significantly different from each other; all others are (Nonparametric Friedman and Conover tests, alpha = 0.05). N = 72 for each.

Stimuli and Subjective Rating Scales

All three stimuli in this study were passive (i.e. during stimuli participants simply watched the monitor and were not required to respond). All tasks lasted approximately 170 seconds. A forced attention task (CRH = cross-hairs) was made in Macromedia Flash Professional 8; it entailed watching a red cross hairs on a white screen with the following instructions: "In a moment you will be asked to perform a control task: you will look directly at the centre of some cross hairs in the middle of the screen for three minutes. Please do your best to look directly at the cross hairs. You should be comfortable while doing this, and you can blink when you need to."

The interesting task (OK) was watching a music video ("This Too Shall Pass", Rube Goldberg version, by the band OK Go) lasting 120 seconds and preceded by a training stimulus of 50 seconds of "TV snow" and white noise. The boring task (IPSK) was watching an unchanging (but

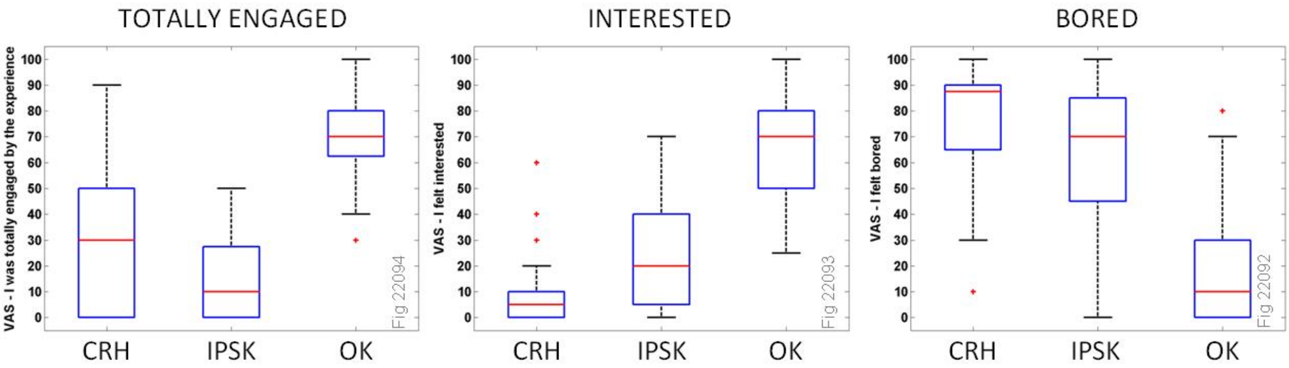


Figure 3. Subjective ratings of stimuli on a 0-100 scale for VAS. Note that the forced attention task (CRH) has lower interest ratings and higher bored ratings than the nominally boring task (IPSK), but that forced attention led to higher engagement ratings. The interesting music video (OK) was most interesting and least boring. N = 24 for all.

arousing) photograph of a skier (IAPS photo 8030) for 2 minutes, preceded by the training stimulus above. Both of these stimuli have been described previously [7].

After experiencing each stimulus, participants made visual analogue scale (VAS) subjective ratings about their feelings during the stimulus for 18 descriptors. Each VAS ranged from 0 ("not at all") to 100 ("extremely") along a 10 cm horizontal scale. The descriptors reported here are, "I was totally engaged by the experience", "I felt bored", and "I felt interested".

Sensors

Body sensors were held in place with elasticated fabric bands with Velcro on both the fabric and the sensor. The sensor nodes used were x-IMU by X-io (Bristol, UK), with 3 dimensions of accelerometry. These sensors are factory calibrated for gravitational acceleration [5]. Data from all nine Micro Electro-Mechanical Sensors (MEMS) in each x-IMU node were recorded at 128 Hz onto the onboard 32 GB micro SD cards (Sandisk Ultra Micro) with the sensors' blue tooth transmission turned off (to extend battery charge). Time alignments between sensors and with other measurements and video tapes were performed using a manual synchronization strategy.

Binary file sensor data was transferred to a Windows 7 computer, and the binary files were converted into csv files using the manufacturer's provided GUI. The csv files were read into Matlab, and all sensor data was aligned (based on the synchronization signals at the beginning and end of the experiment) using a purpose-made script; micro-timing differences between sensors were interpolated linearly – at no point did the original sensor acquisition data differ by more than 50 milliseconds between sensors (over the course of 90 minutes of acquisition). The pre-calibrated data results in 3-D magnitudes, and are high pass filtered (5Hz).

Statistics and analysis

The distributions of subjective ratings are not Gaussian, so non-parametric repeated measures Friedman tests were used [1]. When significant, post-hoc Conover tests [2] were performed, based on:

$$|R_i - R_j| > t_{1-\alpha/2;(n-1)(k-1)} \sqrt{\frac{2k\left(1 - \frac{\hat{\chi}^2_R}{n(k-1)}\right)\left(\sum_{i=1}^{n}\sum_{j=1}^{k} R_{i,j}^2 - \frac{nk(k+1)^2}{4}\right)}{(k-1)(n-1)}}$$

where R is rank, t is the t distribution, χ^2 is the chi-squared distribution, k is number of groups/treatments, n is number of blocks/participants. All effect sizes were assessed using Cohen's *d* (based on N – 1 in the denominator).

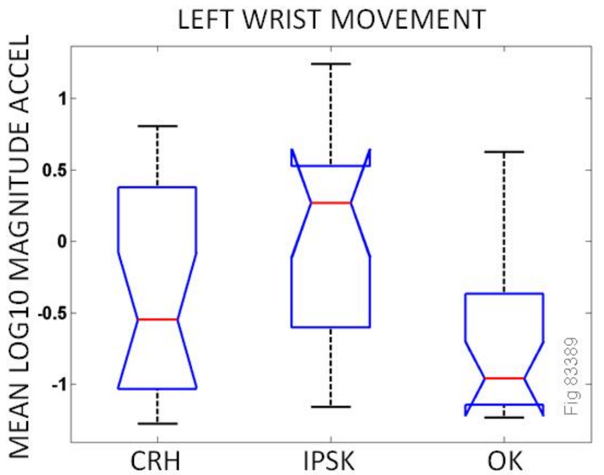
RESULTS

Figure 1 shows representative data from the left wrist during 180 seconds of one stimulus. Panel A shows the raw data, and panel B shows the high-pass filtered 3-D accelerometry magnitude data. In this data the participant was very still except for four brief periods of postural readjustment. To avoid measuring artefacts when the stimulus starts and stops (see large fidget at time 0), a computer-selected 80-second sub-region (between the dashed lines) is always used for calculations [see 6].

Figure 2 compares the movements of the wrists and ankles detected during all stimuli. As very low levels of average movement are the norm, these are plotted on a logarithmic scale. Over 60% of wrist movement and 75% of ankle movement had an average value of < 1; however, a few participants responded with average movement levels that are many times higher (one person jigging her right ankle had a value of 75). A repeated measures Friedman test with post hoc Conover tests shows that all are significantly different, except the left and right wrists. We did not expect the left and right ankles to be different, but in paired analyses, the right side of our participants moved significantly more than the left side. However, the effect sizes between left vs. right (Cohen's *d* < 0.16 for both) is much smaller than for wrist vs. ankle (Cohen's *d* > 0.3 for all comparisons).

To determine the effect of different subjective states (e.g.

interest) on NIMI we re-verified that our stimuli elicited the responses we expected (Figure 3). A Friedman test with Conover post hoc tests showed that for interest, boredom and engagement, all three stimuli were significantly different from each other ($P < 0.05$). It is worth noting that the forced attention task (CRH) has a higher rating of engagement than the boring task (IPSK), yet it is rated as less interesting and more boring.



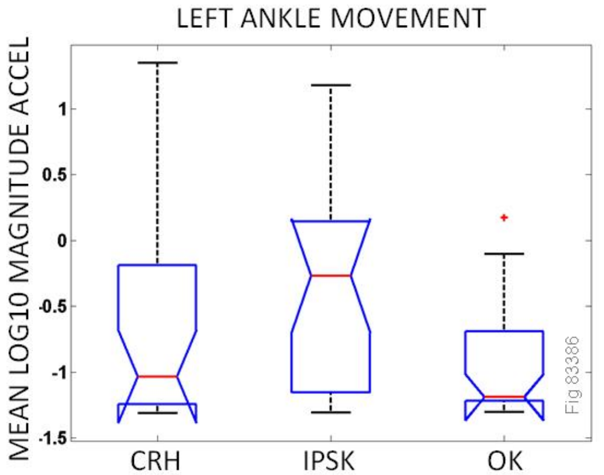


Figure 4. Forced (CRH) and free-willed (OK) engagement elicit less fidgeting than boredom (IPSK). Y axis shows log10 of mean high pass filtered (5 Hz) magnitude of accelerometry signals. In upper panel both OK and CRH are significantly different from IPSK (Nonparametric Friedman and Conover tests, alpha = 0.05). N = 24 for each. Cohen's *d* for OK vs. IPSK was between 0.4 and 0.83 for all four sensors (limbs).

Figure 4 shows the measurements of left limbs' movement (on a logarithmic scale) for all volunteers in response to the different stimuli. Similar patterns appeared for the right side. Movement during OK (music video) was statistically significantly diminished (NIMI occurred) compared to IPSK (boring stimulus) in all limbs except the left ankle. CRH (forced engagement) was only significantly different in one instance: in the left wrist, CRH elicited less movement than IPSK. Although OK was significantly more interesting, more engaging, and less boring than CRH, their elicited movements were not significantly different, re-affirming that NIMI is more strongly related to screen engagement rather than to interest, as per head movements [8]. Spearman correlations of magnitude wrist acceleration vs. VAS rating were all significant (bored: rho = 0.31, $P < 0.001$; interest: rho = -0.21, $P < 0.05$; engaged: rho = -0.22, $P < 0.05$).

CONCLUSIONS

We conclude that wearable sensors on the wrist and ankles provide potentially useful measurements of fidgeting of seated individuals during passive digital interactions. The movements detected during these digital experiences show that wrists move significantly more than ankles, although there are situations of extreme movement (e.g. leg jigging) where the ankles move more than the wrists. These sensor measurements suggest that NIMI not only affects the head and torso, but also relates to the hands and feet, and that NIMI is more related to screen engagement than to interest.

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